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An Ghníomhaireacht um Chaomhnú Comhshaoil

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Past, Current and Future Interactions between Pressures, Chemical Status and Biological Quality Elements for Lakes in Contrasting Catchments in Ireland (ILLUMINATE)

STRIVE

Environmental Protection Agency Programme

2007-2013

SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

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EPA STRIVE Programme 2007–2013

Past, Current and Future Interactions between Pressures, Chemical Status and Biological Quality Elements for Lakes in Contrasting Catchments in Ireland (ILLUMINATE)

(2005-W-MS-40)

STRIVE Report

End of Project Report available for download on http://erc.epa.ie/safer/reports

Prepared for the Environmental Protection Agency

by

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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A successful outcome to ILLUMINATE (Past, current and future **I**nteractions between pressures, chemica**L** status and biologica**L** q**U**ality ele**M**ents for lakes **IN** contr**A**sting catchmen**T**s in Ir**E**land) would not have been possible without the support and help of numerous individuals and institutions. The authors would like to thank in particular Alice Wemaere of the EPA and external members of the project steering committee for their guidance and support throughout the project. Thanks are also due to several colleagues for their assistance with field and laboratory work, to several institutions and individuals for permitting use of their data, to Guangjie Chen for the cladoceran analyses, to Fergal Nugent, Áine Gormley and Theresa Hughes for help with geochemical analysis, to Suzanne Linnane and colleagues at Dundalk Institute of Technology for allowing levels of sediment-based pigment remains to be determined using their facilities, to the C4I team at Met Éireann and to the Rossby Centre (Swedish Meteorological and Hydrological Institute) for provision of future climate data, to the University of Western Australia for use of the model DYRESM CAEDYM, to Conservation Services (Kerry) for access to data and reports on the Killarney lakes and to the numerous landowners, estate managers and Marine Institute staff who facilitated access to the study sites.

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Executive Summary

The Environmental Protection Agency (EPA)-funded ILLUMINATE (Past, current and future **I**nteractions between pressures, chemica**L** status and bio**L**ogical q**U**ality ele**M**ents for lakes **IN** contr**A**sting catchmen**T**s in Ir**E**land) project demonstrates the benefits of integrating past, current and possible future ecological conditions, and underpinning factors, within a dynamic computer modelling framework. The approach is of direct relevance to the Water Framework Directive (WFD) and therefore to River Basin District (RBD) managers and environmental regulators. Three case study catchments were selected as they were relatively rich in high-quality ecological, climatic and hydromorphological data and because they had contrasting catchment characteristics and pressures:

1. Leane (South Western River Basin District (SWRBD));

2. Burrishoole (Western River Basin District (WRBD)); and

3. Mask (WRBD).

The ILLUMINATE End of Project Report[1] is available at http://erc.epa.ie/safer/reports.

A synthesis of the ILLUMINATE results is outlined in Table 1, in accordance with the three aims of the project:

1. Establish reference conditions and determine aquatic ecological responses to particular and combined pressures in the relatively recent past;

2. Use coupled dynamic ecological pressure-response models in combination with existing and new data to produce and evaluate simulations of past and future scenarios that are of direct relevance to the implementation of the WFD in Ireland; and

3. Provide informed comment on the 'at risk' characterisation of the study lakes, where possible.

To fulfil the first aim the research relied heavily upon palaeolimnology. Sediment cores were collected from a total of five lakes: Leane, Muckross, Bunaveela, Feeagh and Mask. Radioactive isotopes provided estimates of the time period covered by each sediment core. Chemical and biological evidence for Muckross indicates relatively long-term ecological stability and the persistence of oligotrophic conditions over a centuries-long timescale. For Leane, available evidence indicates that nutrient enrichment (associated with untreated sewage) from the early 1960s forced a transition to meso-eutrophic conditions. Low nutrient levels prevailed at Feeagh and Bunaveela in the Burrishoole catchment until the onset of mesotrophic conditions associated with afforestation and overgrazing in, respectively, the mid-1950s and 1980s. Overall the evidence from Mask reveals that nutrient enrichment of the lake began as early as the 19th century. Nutrient enrichment is also evident from the late-1950s, and appears to have been associated with increased livestock densities.

A modelling approach that combined catchment with in-lake physical and biological models was deployed in Leane, Feeagh and Mask to produce and evaluate simulations of past and future conditions. This enabled detailed exploration of links between ecological pressures and effects and re-evaluation of the risk characterisations, and facilitated examination of the possible impacts of future climate changes and alterations in land management and population. For all three lakes, modelled variations in past in-lake levels of total phosphorus accorded with measured sediment phosphorus. Moreover, modelled changes in past lake water temperature indicated that warming had occurred in recent decades, and the existence of a significant positive association with the North Atlantic

1. Dalton, C., Jennings, E., Taylor, D., O'Dwyer, B., Murnaghan, S., Bosch, K., de Eyto, E. and Sparber, K., 2010. *Past, current and future Interactions between pressures, chemicaL status and bioLogical qUality eleMents for lakes IN contrAsting catchmenTs in IrEland (ILLUMINATE).* EPA/ERTDI Project No. 2005-W-MS-40 Report. 290 pp.

Table 1. Synthesis of ILLUMINATE results.

1. Reference Conditions and Pressures			
Lake	**Estimated age of base of dated core**	**End of reference conditions, onset of pressures**	**Drivers**
Muckross	–	–	–
Leane	c. 1940	c. 1960s	Sewage discharge 1960–1980 Diffuse agriculture sources 1980+
Feeagh	c. 1895	c. 1950s	Afforestation
Bunaveela	c. 1890	c. 1980s	Overgrazing/Afforestation
Mask	c. 1879[1]	c. 1950	Livestock increases 1950/1960

2. Model Simulations

Hindcast models
- Variations in past in-lake levels of total phosphorus accorded with measured sediment phosphorus
- Changes in past lake water temperature indicated that warming had occurred in more recent decades
- Modelled output generally replicated monitored water quality data for Leane

Model future predictions
- Demonstrated increases in annual air temperature/changes in precipitation driving variations in streamflow and sediment loading and winter increases and spring/early-summer declines in phosphorus loading
- Indicated the potential for increases in phytoplankton biomass and a shift in maximum biomass to earlier in the year in Leane and increases in dissolved organic carbon in Feeagh

3. 'At Risk' Characterisation		
Lake	**Original classification**	**Revised/Validated classification**
Muckross	'Probably not at significant risk'	'Probably not at significant risk'
Leane	'At significant risk'	'At significant risk'
Feeagh	'Probably not at significant risk'	'At significant risk'
Bunaveela	n/a[2]	
Mask	'At significant risk'	'At significant risk'

[1]South-west basin core.
[2]Bunaveela was too small (<50 ha) for inclusion in the characterisation exercise.

Oscillation (NAO). For Leane in particular, modelled output revealed increasing levels of chlorophyll *a* in the period to the 1970s and generally replicated measured water quality. Modelled annual levels of chlorophyll *a* for Mask increased substantially from 1950 through to the 1990s. The models were run incorporating future climate projections and land management scenarios. An increase in annual air temperature and a change in precipitation drove in-lake winter increases and spring/early-summer declines in dissolved phosphorus and total phosphorus loading to Leane, Feeagh and Mask. The changes were attributed to variations in streamflow and sediment loading. Moreover, simulations of in-lake responses for Leane suggested an overall increase in chlorophyll *a* and the development of eutrophic conditions. For Feeagh, predicted changes in water temperature were modelled to lead to increased levels of dissolved organic carbon, thus affecting aquatic biota and causing problems for water treatment.

The empirical data and modelled output generated through ILLUMINATE suggest that the original characterisation of Leane and Mask as 'at significant risk' of not meeting the requirements of the WFD is well founded. However, while the available evidence supports the characterisation of Muckross as 'probably not at significant risk', the same cannot be said for Feeagh in the Burrishoole catchment. Rather, this site would appear to be at significant risk of not meeting the requirements of the WFD because of the continued presence in the catchment of the responsible drivers (afforestation and erosion).

ILLUMINATE acts as a demonstration of the utility and potential benefits of combining computer-based modelling of catchment and associated lake ecosystem conditions and links with other data sources. Work carried out through ILLUMINATE, by developing scenarios that incorporate both land-use and climate changes and that are relevant to the management of surface waterbodies, provides a means of anticipating future aquatic pressures and their effects and of identifying lakes that are of particular risk of not meeting the WFD objectives by the end of the current implementation period (i.e. 2015). The approach adopted in ILLUMINATE is flexible, applicable to other catchments in Ireland and farther afield, and readily updatable as new technologies and data become available.

1 Introduction

Ireland was committed from a relatively early stage to ensuring that the nation's waterbodies will, as a minimum, meet the European Union (EU) Water Framework Directive (WFD) criteria for good ecological status by 2015. An assessment of human pressures and impacts on waterbodies in Ireland identified those waters that were at risk of not meeting all of the criteria for good status (Anonymous, 2005). Uncertainty was, however, attached to the assessment, which, among other weaknesses, did not incorporate future environmental change scenarios. This outcome was not unique to Ireland, however: uncertainty in assessments of risk of not meeting WFD obligations has been identified as a source of major concern generally, with the factors that underpin the uncertainty seen as particularly deserving of further research (Heiskanen and Solimini, 2005).

The Environmental Protection Agency (EPA)-funded ILLUMINATE (Past, current and future **I**nteractions between pressures, chemica**L** status and bio**L**ogical q**U**ality ele**M**ents for lakes **IN** contr**A**sting catchmen**T**s in Ir**E**land) project aimed at addressing the WFD-relevant knowledge gaps identified by Heiskanen and Solimini (2005) at three lake catchments in Ireland. Making the most effective, environmental policy-relevant use of research infrastructure and ecological and environmental data, ILLUMINATE had three aims:

1. To establish reference conditions and to determine aquatic ecological responses to particular and combined past pressures in the relatively recent past;
2. To use coupled dynamic ecological pressure-response models in combination with existing and new environmental information to produce and evaluate simulations of scenarios that are of direct relevance to the implementation of the WFD in Ireland; and
3. To provide informed comment on the 'at risk' characterisation of the study lakes, where possible.

Three case study catchments (Burrishoole and Mask, Co. Mayo, and Leane, Co. Kerry) (Fig. 1.1) were selected as being relatively rich in high-quality ecological, climatic and hydromorphological data sets of direct relevance to the WFD. The lakes associated with the study catchments represent two 'at risk' categories, as described in Anonymous (2005). These 'at risk' categories refer to the likelihood of individual waterbodies not meeting the environmental quality objectives of the WFD by the end of the current implementation period (i.e. by 2015). Four categories were recognised in the characterisation report:

1. At significant risk;
2. Probably at significant risk;
3. Probably not at significant risk; and
4. Not at significant risk.

The case study catchments include examples of lakes 'probably not at significant risk' (Feeagh, Muckross) and 'at significant risk' (Leane, Mask). Moreover, the catchments chosen support contrasting levels of population densities and intensities of farming and afforestation, and over time have been subject to a variety of pressures, including acidification, nutrient enrichment, organic loading and other forms of pollution, land-cover change and associated erosion, and climate change.

ILLUMINATE has been a joint research effort, involving collaboration between Trinity College University of Dublin, the University of Limerick, University College London, the University of Ulster, the Newport Research Laboratory of the Marine Institute, Kerry County Council/(South Western River Basin District) SWRBD, the Environmental consultancy firm ESB International (ESBI) and the Western River Basin District (WRBD). The project was divided into four integrated work packages (WPs):

1. WP1 collated existing data sets for the three case study catchments and examined available

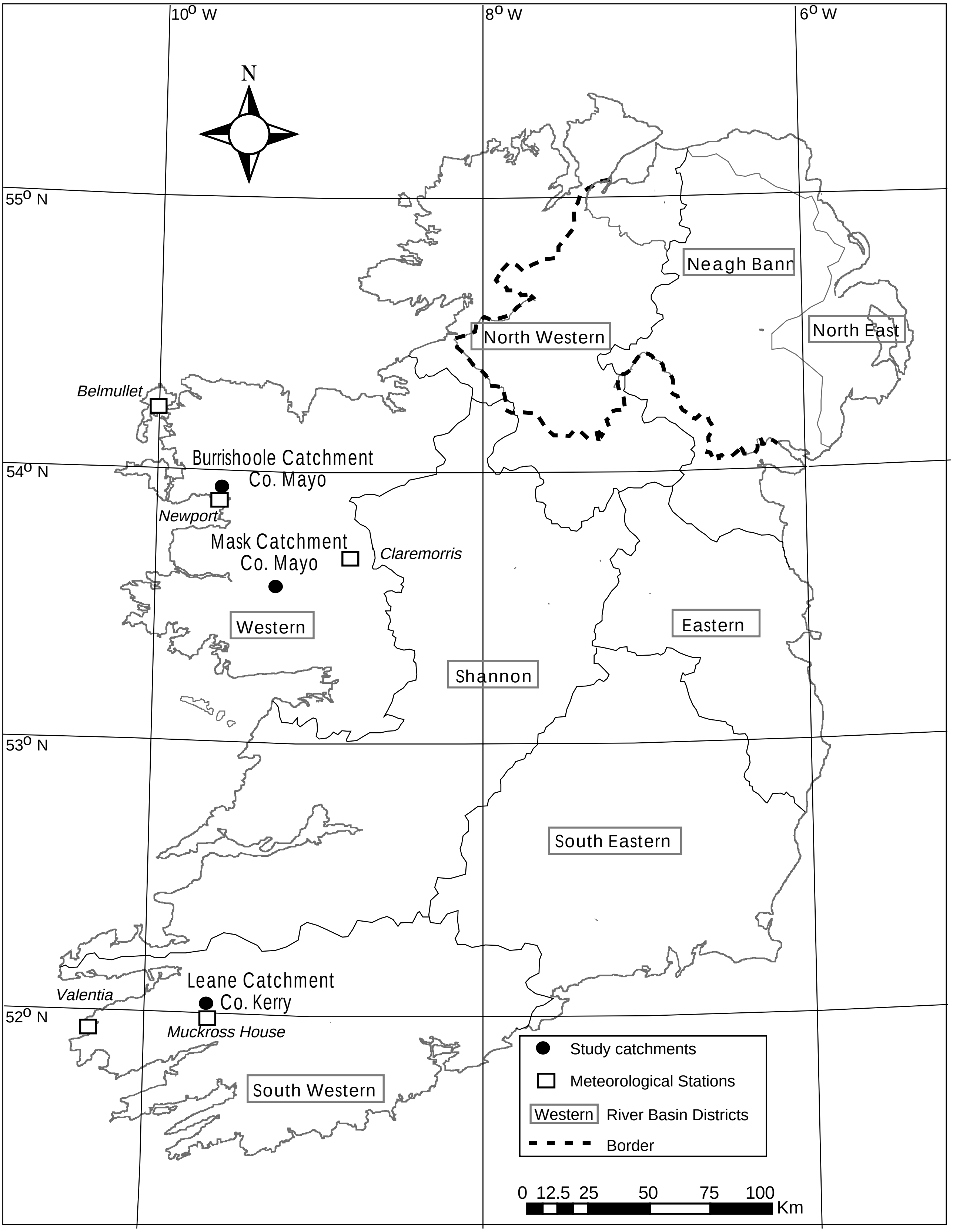

Figure 1.1. The three ILLUMINATE case study catchments and the eight River Basin Districts in the Irish ecoregion (Ecoregion 17). Also shown are the locations of the closest meteorological stations, and the Ireland–Northern Ireland (UK) border.

catchment pressure and ecological response models;

2. WP2 utilised palaeolimnological methodologies to establish reference conditions and past variations in ecological pressures and responses for the lakes studied;

3. WP3 integrated data sets and employed dynamic computer models to produce and evaluate simulations of past and future scenarios and their aquatic effects; and

4. WP4 disseminated the results via a demonstration workshop (see Appendix 1), seminars, conference presentations, doctoral theses (see Appendix 2) and EPA reports, including this synthesis report.

The following chapters of this report summarise the approaches adopted in and the main findings from ILLUMINATE. More detailed treatment is provided in the End of Project Report (Dalton et al., 2010) available at http://erc.epa.ie/safer/reports).

2 Study Catchments and Lakes

The study catchments are located in two RBDs: the SWRBD (Leane) and the WRBD (Burrishoole and Mask). Detailed descriptions of the study catchments, the physical and biological characteristics of the associated lakes and potential drivers of aquatic ecosystem change can be found in the End of Project Report (Dalton et al., 2010) available at http://erc.epa.ie/safer/reports.

2.1 Leane (SWRBD)

The Leane catchment (52° 03' N, 9° 32' W) (Fig. 2.1), covering c. 550 km^2, has been the focus of attention for many years owing to its importance for tourism and angling. Land cover mainly comprises upland peat, pasture and forestry, while climatically the catchment is characterised by cool temperate, oceanic conditions. Substantial increases in human population density and associated infrastructure have occurred over the last c. 50 years, while stocking levels of cattle and sheep have risen sharply, respectively, from the 1970s and in the 1990s (CSO, 1997). Afforestation, almost entirely restricted to upland peat soils, during the 1970s is also likely to have impinged upon catchment stability and aquatic conditions.

The two main lakes in the catchment, Muckross (Fig. 2.2) and Leane, are classed as, respectively, Type 4 and Type 8 in the EPA's classification of lakes in Ireland (a typology that is based on hydromorphology and water chemistry: Type 4 lakes are >3 m deep, have a large surface area (>50 ha) and low alkalinity, whereas Type 8 lakes are >3 m deep, and are large and moderately alkaline).

According to the recent characterisation report for Ireland (Anonymous, 2005), Muckross is characterised as 'probably not at significant risk' while Leane is

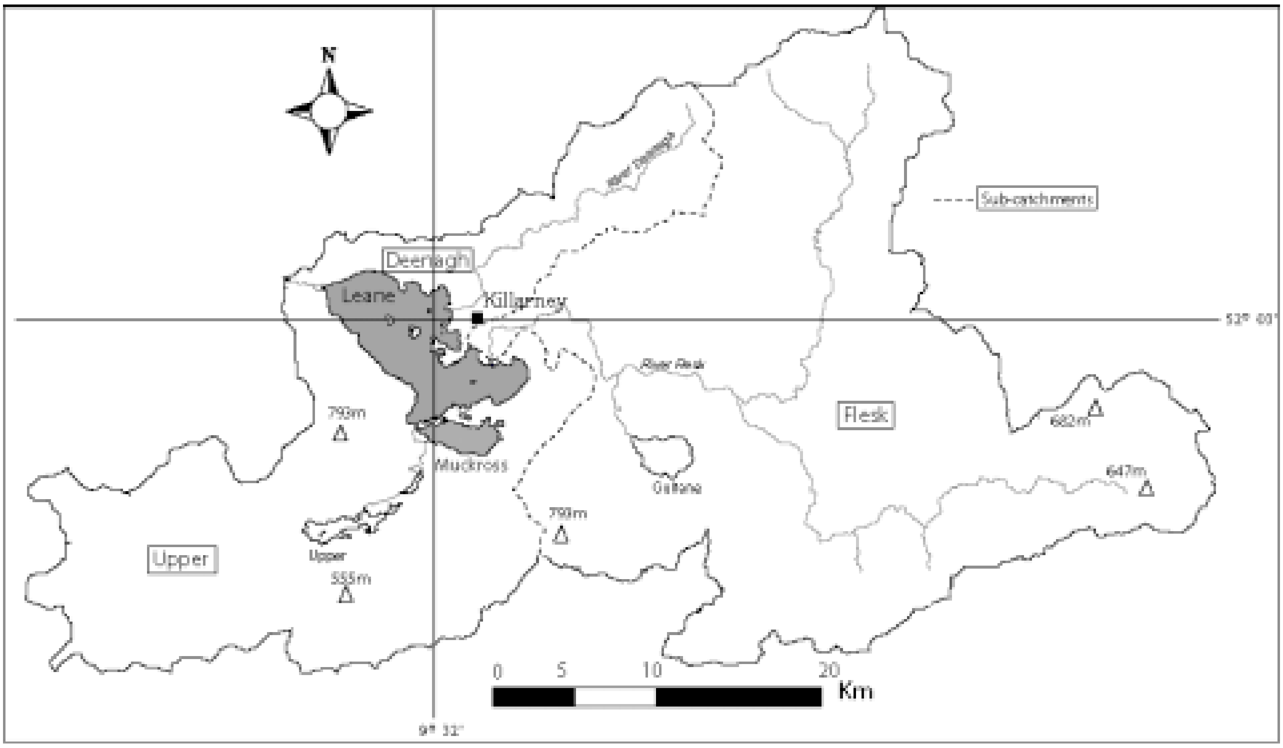

Figure 2.1. The Leane catchment, showing the location of Leane and Muckross and the main sub-catchments (Upper, Deenagh and Flesk).

Figure 2.2. Muckross, Leane catchment.

classed as ‘at significant risk’. Concerns were first raised about water quality in Leane in 1967 (Fehily and Shipman, 1967), with eutrophication being repeatedly reported over the last two to three decades (KMM 2000, 2003; Twomey et al., 2000, 2001; Jennings et al., 2008).

2.2 Burrishoole (WRBD)

The Burrishoole catchment (53° 56' N, 9° 35' W), covering c. 100 km^2 (Fig. 2.3) of generally extensively grazed upland peat soils and coniferous plantation forestry and climatically influenced by the Atlantic Ocean (Allott et al., 2005), is internationally important as an index site for salmonid monitoring (Whelan et al., 1998). Human population densities are low, with afforestation and overgrazing by sheep key drivers of change in catchment and aquatic ecosystem conditions. Commercial plantations, first established in 1951, were extended in the 1960s. Stocking levels of sheep increased sharply from the early 1970s as a result of EU subsidies (Gillmor and Walsh, 1993), but have declined since the beginning of the current century.

Bunaveela and Feeagh (Fig. 2.4), the two largest freshwater lakes in the catchment and categorised as, respectively, Type 3 and Type 4 in the EPA’s lake typology, are both deep, oligotrophic and coloured because of high levels of dissolved organic carbon (DOC), and have low alkalinity.

According to Anonymous (2005), Feeagh is regarded as ‘probably not at significant risk’, while in 2003 the lake was classed as a candidate reference lake by the EPA. Bunaveela, a headwater lake and considerably smaller in surface area than Feeagh, was too small for inclusion in the characterisation report. Several studies have highlighted degradation of the Burrishoole catchment associated with afforestation and overgrazing (e.g. Allott et al., 2005; May et al., 2005) in the past five decades, but the impact of this degradation on fish stocks remains a subject of debate.

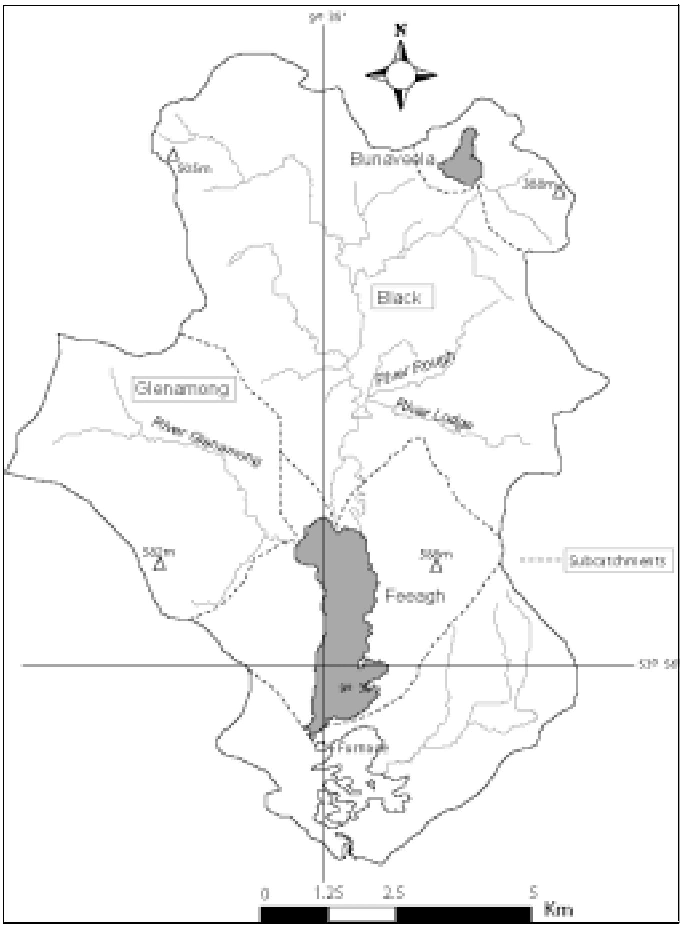

Figure 2.3. The Burrishoole catchment showing the locations of Bunaveela and Feeagh and the main sub-catchments (Glenamong and Black).

Figure 2.4. Feeagh, Burrishoole catchment.

2.3 Mask (WRBD)

The Mask catchment (53° 36' N, 9° 22' W) (Fig. 2.5) comprises over 850 km^2 of acidic peat soils blanketing upland areas in the western part of the catchment and lowland, intensively farmed, calcareous soils to the east. Climatically the catchment is characterised by cool temperate, oceanic conditions. With a surface area of c. 8,200 ha, Mask (Fig. 2.6) is more than four times larger than Leane, the next largest lake studied in the ILLUMINATE project. Mask is recognised as one of the most important natural wild brown trout fisheries in Europe, being particularly noteworthy for its large population of Arctic char and charophyte populations (McGarrigle and Champ, 1999). Human population densities were at their highest at the beginning of the 20th century and have since declined. Stocking levels of sheep were also relatively high in the early part of the 20th century, increasing further from 1980 and peaking in 2000 (CSO, 1997). Cattle numbers increased in the early 1900s and in the 1960s.

According to the EPA typology, Mask is classed as a Type 12 lake (>3 m deep, >50 ha and highly alkaline). However, the western parts of the lake are far more acidic in nature, due to the influence of run-off from adjacent base-poor upland areas. Moreover, Mask is bathymetrically complex, and actually occupies several sub-basins. Monitoring data for Mask indicate a deterioration in water quality over the last c. 20 years, during which time the trophic status of the lake has changed from oligotrophic to mesotrophic (Toner et al., 2005). The lake was characterised as 'at significant risk' of not meeting WFD objectives by the end of the current implementation period (Anonymous, 2005).

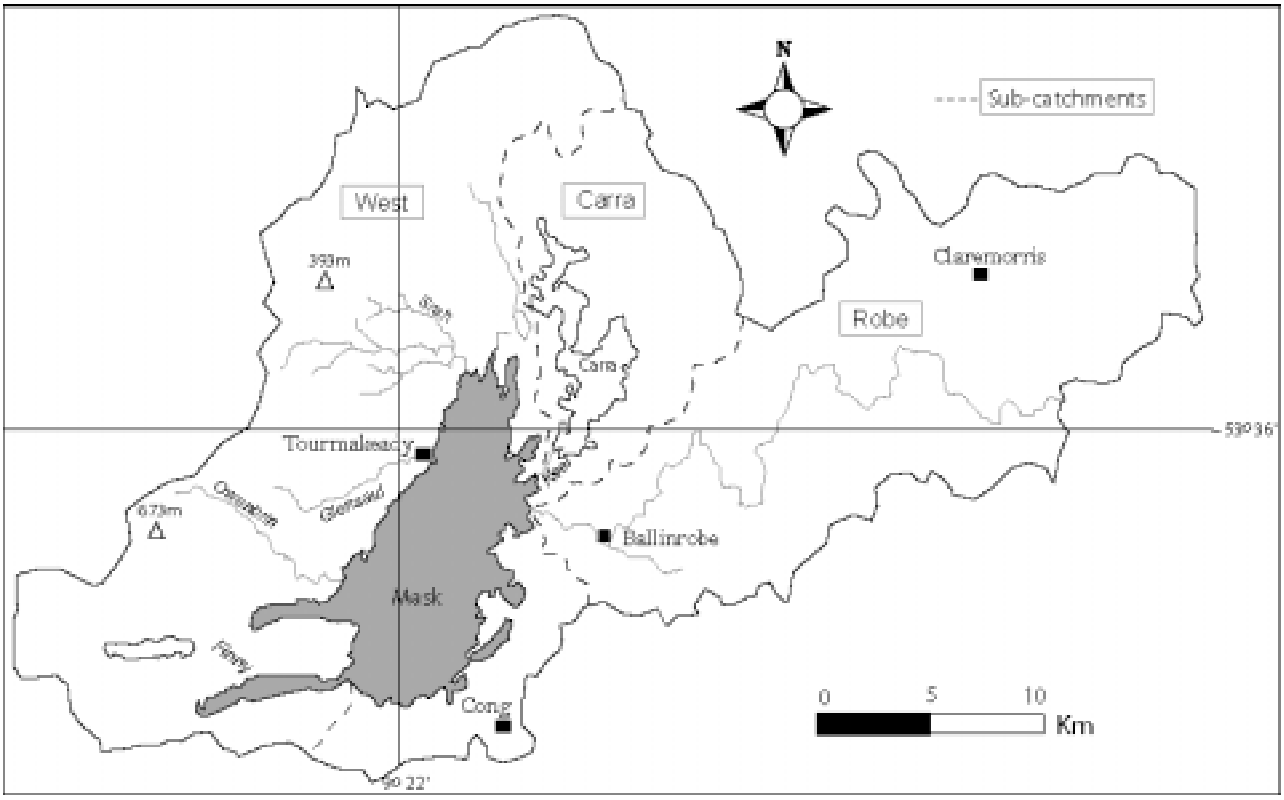

Figure 2.5. The Mask catchment, showing the locations of Mask, principal urban areas in the catchment, key inflow rivers and sub-catchments. The Keel Canal links loughs Carra and Mask.

Figure 2.6. View from eastern shoreline of Mask.

3 Reference Conditions and Past Ecological Responses of Study Lakes to Particular and Combined Pressures

When applied to a lake, reference conditions are the biological and chemical characteristics of the waterbody that existed prior to human impact. They can be established directly from extant examples of waterbodies showing no effects of human modification. Such examples are rare in many European countries, however, including Ireland. Alternatively, reference conditions can be reconstructed, either from long-term monitoring data or from the remains of aquatic biota and accompanying evidence of environmental conditions preserved in lake sediments. Sediment-based remains of aquatic plants and animals can be used directly to recreate past aquatic life assemblages, or they can be used in combination with statistical techniques known as transfer functions to quantify past water quality. The use of lake sediments in this way is an increasingly important part of the scientific discipline of palaeolimnology. Because of a dearth of information on aquatic ecological conditions in the study catchments prior to the onset of human-induced environmental modifications, the determination of reference conditions and subsequent responses to ecological pressures in ILLUMINATE relied heavily upon palaeolimnology. Information obtained through palaeolimnology complemented recent environmental change and current ecological data. Palaeolimnology utilises components of lake sediments – both biological and non-biological – to reconstruct past drivers of aquatic ecological change and their effects. Palaeolimnology thus provides a means not only of defining a reference state in the absence of extant examples of conditions or long time series of data from monitoring, but also of establishing the degree of change away from a defined reference state, as well as the cause(s) and rate of that change.

Reference conditions and past and current variations in ecological pressures and responses for the last c. 100–200 years were reconstructed for lakes in the three case study catchments using palaeolimnological techniques. This involved the collection of multiple cores of sediment using a gravity corer, in order to minimise disturbance and contamination. Sediment cores were collected from a total of five lakes (Leane, Muckross, Bunaveela, Feeagh and Mask) in the three study catchments. Laboratory analyses of abiotic and biotic components of the sediment sequences followed, thus enabling reconstructions of up-core (through time, with the lowermost sediment samples in a core assumed to be older than those higher up the profile) variations in aquatic plant and invertebrate life, and in important chemical elements. Allochthonous material, transported to a lake by water and/or the atmosphere, in the cores was also analysed.

In order to facilitate interpretation and intra- and inter-site comparisons of palaeolimnological data, the rate of sediment accumulation at each coring site – and therefore the approximate age of different sediment sample depths – was established using several dating techniques. These dating techniques generally relied upon the known rate of decay of radioactive isotopes that occur in lake sediments. A high degree of inter-site variation in rates of sediment accumulation was evident following dating of the sediment cores. The lowermost sediment samples obtained from Leane, Bunaveela, Feeagh and a basin in the south-west of Mask dated to, respectively, c. 1950, c. 1890, c. 1895 and c. 1870. By contrast, rates of sediment accumulation at Muckross and two sites at Mask (the eastern and western/central basins) appeared very low, and the time period of most interest to the current research – the last 100–200 years or so – was represented by only the uppermost few centimetres of sediment. Detailed descriptions of both field and laboratory methods deployed in ILLUMINATE are provided in the End of Project Report (Dalton et al. 2010) available at http://erc.epa.ie/safer/reports.

3.1 Leane Catchment

Lake water quality and associated aquatic ecological changes in Leane and Muckross, and their possible drivers, are illustrated in Fig 3.1. Some inwash, possibly as a result of catchment afforestation, is

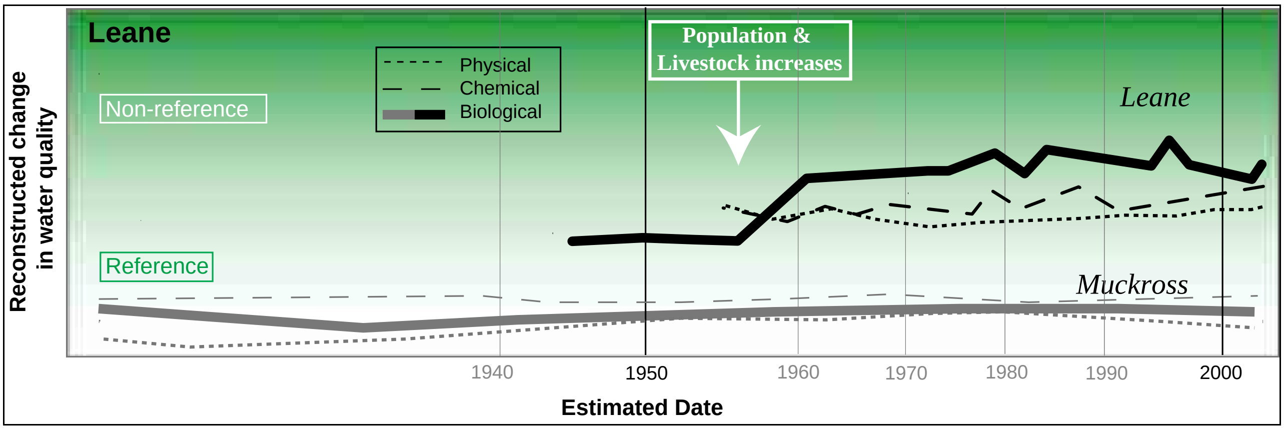

Figure 3.1. Reconstructed variations in lake water quality and their possible drivers c. 1940–2006: Leane and Muckross.

evident in the sedimentary record from Muckross. Overall, however, the palaeolimnological evidence suggests the persistence of oligotrophic conditions throughout the time period covered by the sedimentary record analysed, and therefore that the lake is currently at or close to reference. This is not the case for Leane, however, where nutrient enrichment from the early 1960s forced a transition first to meso-eutrophic and then to eutrophic conditions. Moreover, basal sediments from Leane analysed in ILLUMINATE and dating to the 1940s suggest that the lake was in a state of recovery from an even earlier phase of nutrient enrichment, and therefore the record obtained probably does not contain incontrovertible evidence of reference conditions. Inputs of phosphorus, in the form of untreated sewage from Killarney, are likely to have been a major contributor to eutrophication pressures from the early 1960s and up to the implementation of improvements to sewage treatment plant (STP) facilities completed in the 1980s, after which date diffuse (largely agricultural) sources of nutrients are prominent (Jennings et al., 2008).

Algal responses to nutrient enrichment are evident in increases in concentrations of sediment-based pigments (one of the sedimentary components studied), a switch to more nutrient-tolerant diatom assemblages, and increases in diatom-inferred total phosphorus (DI-TP). Low levels of algal pigments are present until c. 1960. Subsequent peaks appear to coincide with reported occurrences of algal blooms in the early 1970s, mid-1980s and late 1990s (Twomey et al., 2000). Remains of diatoms preserved in the sediments analysed show the early predominance of oligotrophic/circumneutral taxa (e.g. *Achnanthidium minutissimum*), followed from c. 1960 by eutrophic species (e.g. *Aulacoseira subarctica*). This switch is evident in the onset of a more nutrient-enriched state and higher levels of pH (according to, respectively, DI-TP and diatom-inferred pH (DI-pH)). Diatom assemblages in basal core samples suggest that Leane experienced relatively low nutrient levels between c. 1945 and the late-1950s, with DI-TP levels indicative of mesotrophic conditions. DI-TP increases sharply from the early 1960s, suggesting meso-eutrophic conditions. Moreover, the benthic/planktonic Cladocera ratio for Leane is highest in the basal sample (c. 1945), indicating a particularly rich benthic fauna at that time. A change up-core in the abundances of littoral and planktonic forms may be a response to lower water transparency, a decline in available macrophyte habitat, or some combination of the two, and is indicative of reduced ecological status (de Eyto et al., 2003).

3.2 Burrishoole Catchment

Lake water quality and associated aquatic ecological changes in Bunaveela and Feeagh, and their possible drivers, are illustrated in Fig. 3.2.

Neither Bunaveela nor Feeagh is currently in reference state, according to the information obtained through ILLUMINATE. For Feeagh, such a conclusion accords with the results of earlier EPA-funded research (Leira

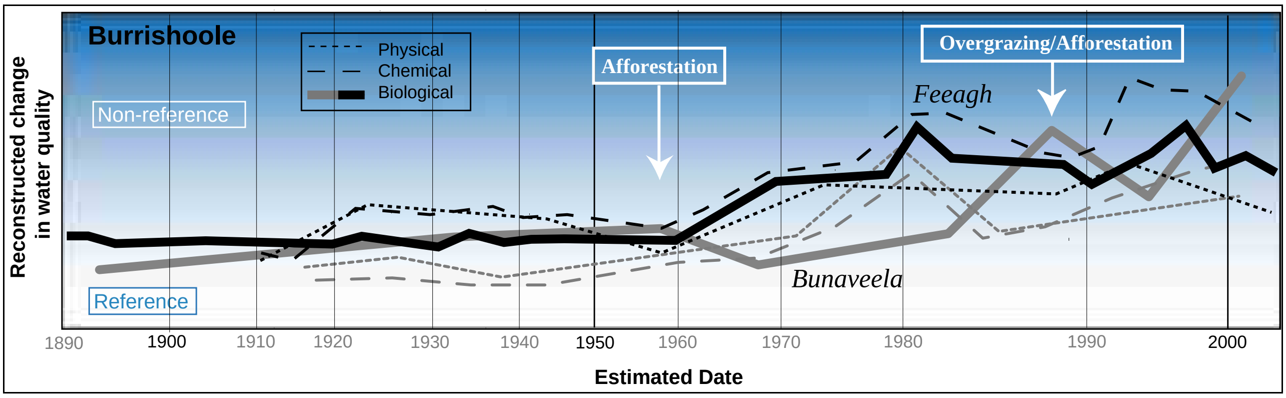

Figure 3.2. Reconstructed variations in lake water quality and their possible drivers c. 1890–2006: Bunaveela and Feeagh.

et al., 2006). According to the sediment-based information obtained, low nutrient levels prevailed at Bunaveela until the 1980s, after which point increased levels of catchment disturbance and nutrient enrichment, apparently associated with afforestation and overgrazing, became evident. The aquatic effects of catchment disturbance and nutrient enrichment appear earlier in the sedimentary record from Feeagh, and date to the mid-1950s. On the basis of DI-TP, Feeagh experienced mesotrophic conditions from the late 1960s, while mesotrophic conditions did not appear at Bunaveela until the late 1980s/early 1990s.

Sediment-based remains of plants confirm a shift in catchment vegetation, and in particular an increase in conifers (presumably part of afforestation in the catchment) around Feeagh from c. 1955 and Bunaveela from the early 1980s. Low concentrations of algal pigments, indicating poor preservation conditions, and generally low productivity characterise the sediments recovered from Feeagh. The remains of diatoms in the sediments analysed record an initial period of nutrient enrichment at Feeagh, dating to c. 1955. A second phase of enrichment, commencing c. 1980, is also recorded at Bunaveela. An increased availability of nutrients, possibly associated with catchment disturbance linked to afforestation and overgrazing, may also have driven changes in cladoceran assemblages and a heightened prominence of planktonic taxa in particular.

3.3 Mask Catchment

Mask was the largest and most complex, geographically and ecologically, of the catchments and lakes studied in the current research. Major intra-lake differences in sedimentation and in the degree of preservation of sedimentary information posed challenges for data collection and interpretation. Cores were collected at Mask from three coring sites. Two of these provided relatively long sedimentary records, in terms of the time period covered, while the third permitted relatively high-resolution reconstructions of environmental variations over the last c. 140 years. Lake water quality and associated aquatic ecological changes in Mask, and their possible drivers, are illustrated in Fig. 3.3.

Combined sedimentary evidence from Mask indicates that low nutrient levels prevailed throughout much of the last c. 6,000 years. Nutrient enrichment may have commenced at a relatively early date, although more certainty is attached to sedimentary evidence of eutrophication from a coring site in the south-western part of Mask that dates to the last 140 years or so. Taken together, the evidence indicates that Mask is not currently in reference state, with reference conditions characterised by a lower availability of nutrients than is the case at present.

According to analyses of sediments from the coring site in the south-western part of Mask, the diatom *Tabellaria flocculosa*, which has relatively low TP and pH optima (Chen et al., 2008), is abundant until the early 1900s, indicating relatively low levels of in-lake

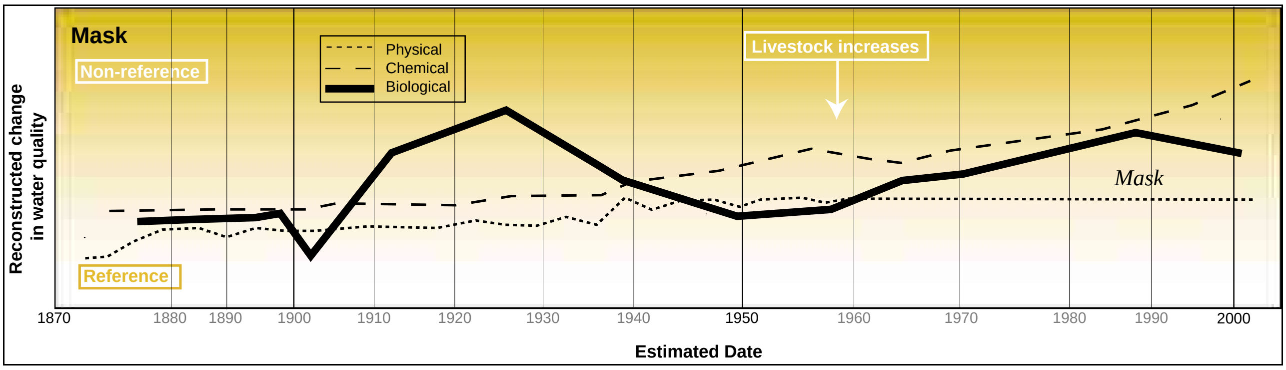

Figure 3.3. Reconstructed variations in lake water quality and their possible drivers c. 1870–2006: Mask.

TP. *Asterionella formosa* and *Fragilaria capucina* are both planktonic species with high and moderate TP optima, respectively (Chen et al., 2008). Both diatoms increase in abundance from c. 1910, presumably because of an increased availability, in-lake, of TP. By c. 1940, *Tabellaria flocculosa* is once again abundant and nutrient availability has declined. *Asterionella formosa* and *Fragilaria capucina* return to abundance, while levels of *Chara* remains decline, from the late 1960s and in the early 1980s. Some recovery in water quality at Mask is evident in the uppermost samples in the sediment core from the coring site in the south-west part of the lake.

Sedimentary evidence from Mask indicates nutrient enrichment possibly commencing long before generally assumed reference baselines for aquatic ecosystems in Ireland. This nutrient enrichment may have been human induced, or possibly climatically driven (or some combination of the two). Alternatively sediment-based evidence of nutrient enrichment at Mask may be more apparent than real, and an artefact of differential preservation of biological remains, owing to fluctuations in water chemistry. Preservation of biological proxies was a problem at all three coring sites, with the remains of diatoms and/or macrofossils being completely absent from some sections of sediment cores.

4 Modelled Ecological Variations and their Drivers

The ILLUMINATE project aimed to demonstrate the use of dynamic modelling in meeting WFD requirements, in particular to reduce uncertainty in risk characterisation and to explore future changes in pressures and ecological responses, thus providing a tool with which to explore potential management options.

The semi-empirical Generalised Watershed Loading Functions (GWLF) model (Schneiderman et al., 2002) was used to simulate past transfers of nutrients and sediments from the catchment to Leane, Feeagh and Mask, while the in-lake models – Dynamic Reservoir Simulation Model (DYRESM) and Computational Aquatic Ecosystem Dynamics Model (CAEDYM) (Imberger and Patterson, 1981) – were used to explore the impact of these changes on in-lake physical and biological conditions in Leane and Mask (Fig. 4.1). In addition, the impacts of future climate change and potential changes in land management and population on nutrient loading were investigated. To facilitate modelling of past conditions, the GWLF model was amended to use time series data for population and land use, and a livestock module was added. The chosen models were validated using historical data for the sites together with new data collected during the project (Dalton et al., 2010). All modelling approaches were, however, restricted by the availability of historical input and validation data.

4.1 Modelling of Past Conditions

Modelling of past transfers of TP from all three catchments showed increases over time, with inter-site differences evident in the onset of these increases. Loads from the Leane catchment increased from a minimum in 1941, peaking in 1974 and 1984. This increase was related in particular to the STP for Killarney (Jennings et al., 2008). The load then decreased from the mid-1980s to the early 1990s, following improvements in treatment at the STP, but increased again in more recent years, with diffuse sources making a substantial contribution to the latter. Nutrient transfers to the Feeagh catchment were relatively stable until the 1960s, after which they increased, although remaining much lower than for Leane, presumably because of differences in human and livestock population densities. The increase

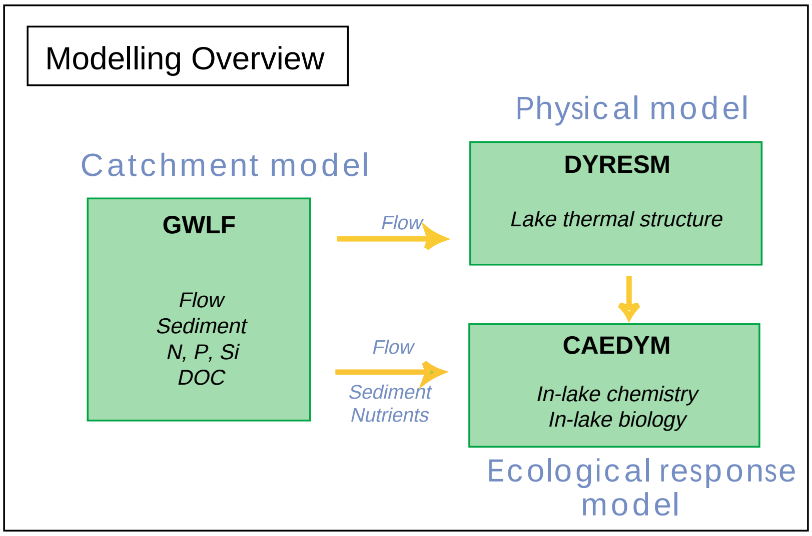

Figure 4.1. Overview of modelling approach adopted in ILLUMINATE. GWLF, Generalised Watershed Loading Functions; N, nitrogen; P, phosphorus Si, silicon; DOC, dissolved organic carbon; DYRESM, Dynamic Reservoir Simulation Model; CAEDYM, Computational Aquatic Ecosystem Dynamics Model.

coincided with land-use changes due to afforestation and to increases in sheep numbers in the 1980s and 1990s. Modelled transfers of TP to Mask were also relatively low and stable from 1900 to 1972. From the early 1970s, loading increased dramatically, peaking in 1999. Modelled transfers of total nitrogen (TN) generally followed similar trends to phosphorus at all sites, but were an order of magnitude higher (Dalton et al., 2010).

Variations in modelled TP transfer and measured sediment phosphorus were in close agreement for all three lakes (Fig. 4.2). Changes in TP loading to Leane and sediment phosphorus accumulation comprised a

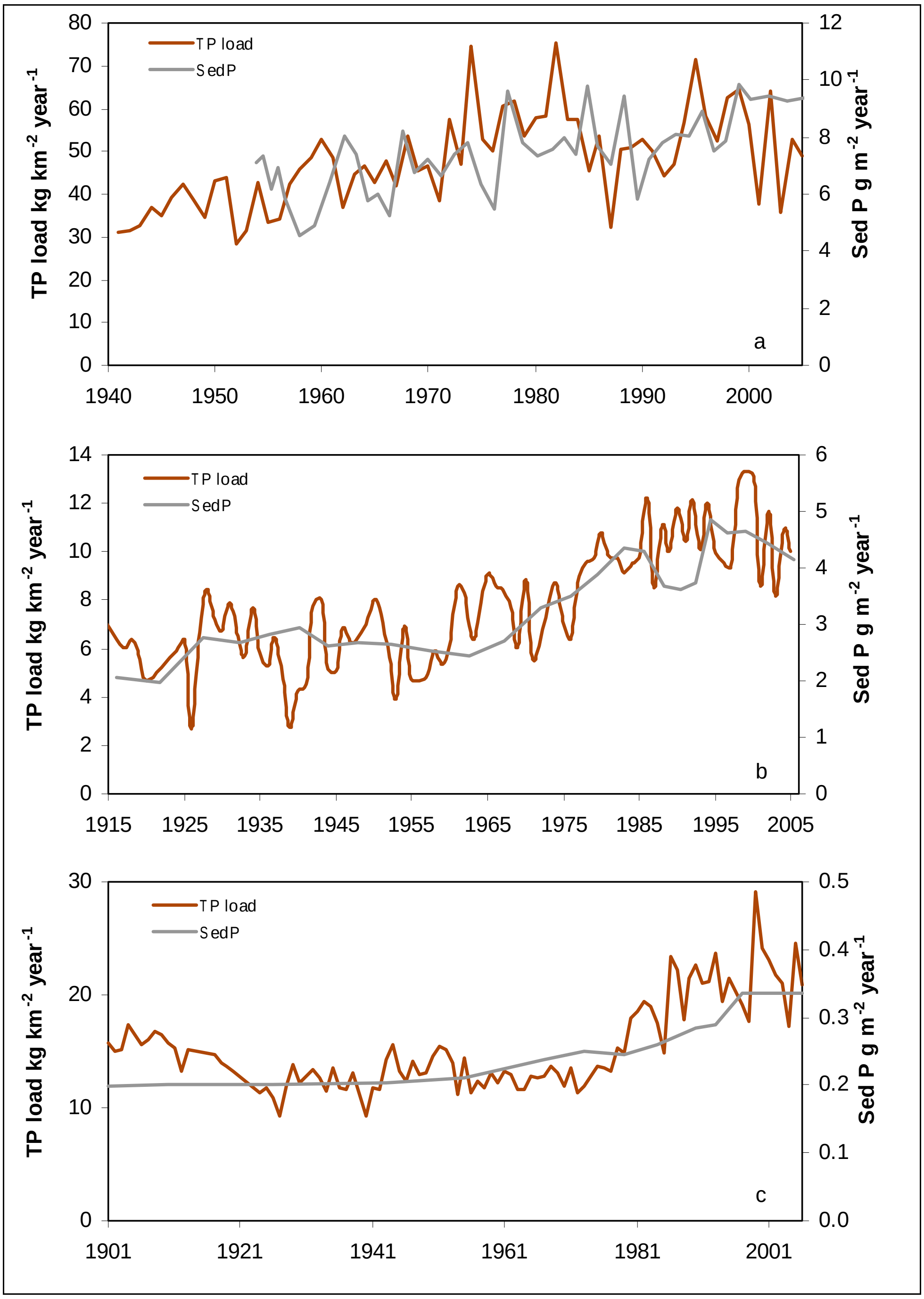

Figure 4.2. (a) Leane, 1941–2005; (b) Feeagh, 1900–2005; (c) Mask, 1900–2005: modelled total phosphorus (TP) loads and sediment phosphorus (Sed P) accumulation.

period of increase from the 1940s to the 1980s, a subsequent decrease and a further increase in the more recent past. Sediment phosphorus accumulation confirmed relatively stable conditions for Feeagh until the 1960s, with subsequent increases evident. Increases in sediment phosphorus and in modelled TP loads for Mask were more recent, occurring over the last 20 years. A significant change point in TP loading was indicated in 1973 for Leane, roughly coinciding with an increase in cattle numbers evident in agricultural censuses, and with increased precipitation (Dalton et al., 2010). For Feeagh, a change point was identified at c. 1960, shortly after initial afforestation in the catchment and just prior to an increase in sheep numbers reported from the 1970s to the 1990s. The change point in the simulated TP load from the Mask sub-catchments was 1978; again, the major change in the model-driving variable was increasing livestock numbers.

The potential impact of these loads and of historical changes in climate were evaluated using a coupled model of in-lake thermal structure (DYRESM) and biological response (CAEDYM) for Leane and Mask. The lake physical model was also run for Feeagh. A significant upward trend in simulated annual surface water temperature over time was evident for all three lakes. However, the simulations also indicated that while Leane and Feeagh stratified in most years, Mask was only weakly stratified or unstratified for much of the period from 1950 to the mid-1960s. Results indicated that Mask was then probably stratified for the period between the mid-1960s and the late 1970s and in the more recent past. The warming trend in summer was, however, stronger in the simulations for Mask and, in contrast to the other two lakes, was apparent in both surface water temperature and deep water temperature. This difference may reflect the more mixed nature of Mask: hypolimnetic waters in a more stratified lake can become isolated from the influence of changes in local weather during stratification.

CAEDYM output for Leane showed increasing annual maximum chlorophyll *a* levels from 1941 to the early 1970s, the period prior to available records, with levels in the mesotrophic range. The model replicated the subsequent decreases after 1984 and the increase to the late 1990s, but not the hypertrophic conditions recorded in Leane in 1997 (Twomey et al., 2000). Cyanobacterial chlorophyll *a* was the main contributor to total maximum in-lake chlorophyll *a*. Diatom abundances generally peaked in spring in the simulations and did not show the same long-term increase as total and cyanobacterial chlorophyll *a*. Hindcast annual maximum chlorophyll *a* concentrations in Mask are relatively low and stable from 1905 to c. 1950, after which concentrations become more variable and increased by as much as three times the values prior to 1950. From the late 1990s, however, simulated chlorophyll *a* decreased substantially. In the early 1900s, the phytoplankton community composition was dominated almost entirely by chlorophytes. This community structure changed from the 1920s onwards, when diatoms became more abundant. Between 1950 and the late 1970s, chlorophytes were generally the second most common algal group, with cyanobacteria comprising a very small minority; cyanophytes became more abundant from the 1980s.

4.2 Future Projections

If no further action is taken to reduce greenhouse gas emissions, the global average surface temperature is likely to rise by a further 1.1°C to 6.4°C this century (IPCC, 2007). The GWLF model was used to investigate the potential impacts of projected changes in climate on seasonal patterns in nutrient loading at sub-catchment level. Accordingly, the Flesk (Leane), Black (Feeagh) and Robe (Mask) sub-catchments were selected for study. A more detailed investigation was also carried out on the impacts of climate, population and land-use changes on both in-lake loadings and ecological responses for Leane. The future climate data used in ILLUMINATE were based on output from different Global Climate Models (GCMs), Regional Climate Models (RCMs) and greenhouse gas emission scenarios for two time periods (2021–2060 and 2071–2100) (Dalton et al., 2010). All future climate projections indicated an increase in annual air temperature, both for 2021–2060 and 2071–2100, with higher increases for the later period. A change in the seasonal pattern of precipitation was also indicated, with general increases in precipitation between October and March and drier weather from late spring to autumn. Again, this seasonal difference was more pronounced for the later period. Simulations of catchment loading based on changes in climate alone for 2021–2060 resulted in increased levels of dissolved phosphorus and TP in late winter, and decreases for spring and early summer. The change in projected dissolved phosphorus loading was driven by changes in streamflow, while that in TP was also related to changes in sediment loading.

For Flesk, 2071–2100, an increase in annual TP loads attributable to climate change was greater than that from either population or land-use change (Fig. 4.3) (Jennings et al., 2009). The seasonal pattern in projected phosphorus export mirrored changes in streamflow, with higher rates between January and April and lower rates in summer. The potential reduction in export in summer was, however, negated when increases in population were included in simulations. A change in the slurry spreading period from that stipulated in national regulations to the months between April and September could potentially mitigate against future increases in dissolved phosphorus export in spring. The results confirm that projected changes in climate should be included when undertaking modelling exercises in support of decision making for catchment management plans.

An increase in monthly mean surface water temperature in Leane was projected for all months of the year. Maximum increases occurred in June and were 3.0°C and 2.3°C for the A2 and B2 greenhouse gas emission scenarios, respectively. The simulations also indicated a potential shift in the peak mean chlorophyll *a* from July to June for the A2 scenario. More importantly, there was an increase in annual maximum chlorophyll *a* concentration for both scenarios, from below 20 mg/m^3 in the control simulations (i.e. mesotrophic) to c. 25 mg/m^3, the boundary for in-lake eutrophic conditions. While the increase in projected maximum chlorophyll *a* was attributed to an increase in the availability of dissolved phosphorus, simulations using different phosphorus loading scenarios indicated that the shift in chlorophyll *a* peaks was probably not due to phosphorus availability. There was, however, an earlier onset of stratification for the A2 scenario, owing to a combination of higher temperatures, higher solar radiation and lower summer wind speed. Overall, stratification commenced 12 days earlier for the warmer A2 simulations than for the B2 simulations.

The impact of projected climate change on the export of DOC was also investigated for the Glenamong sub-catchment (Feeagh). The change in climate for the Burrishoole catchment for the 2071–2100 period

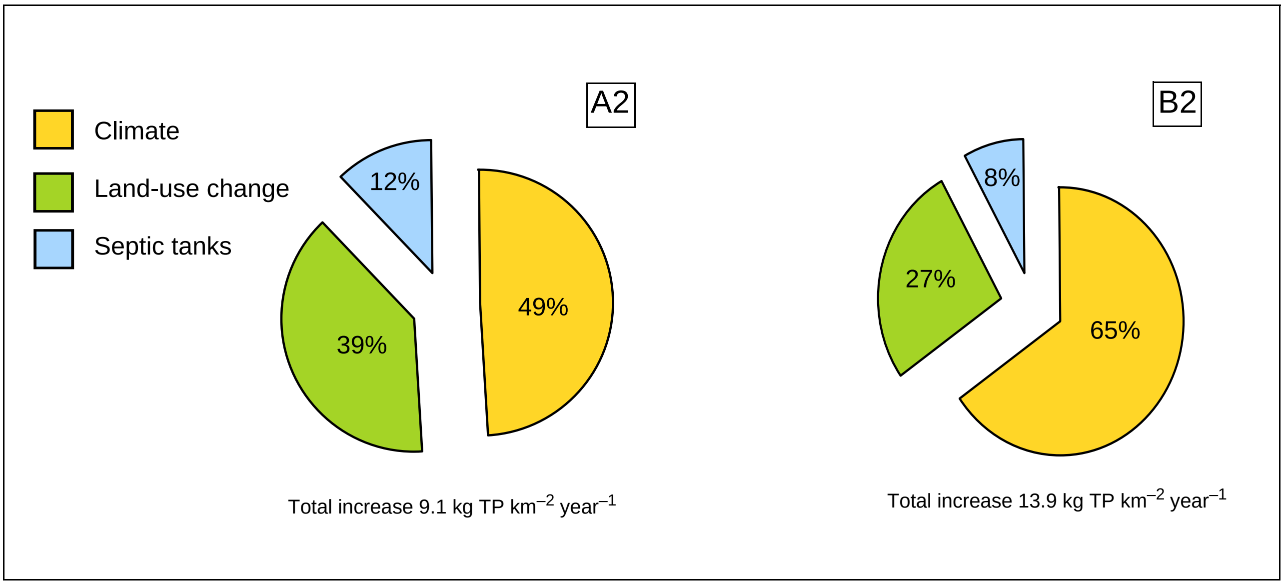

Figure 4.3. Source of the increase in total phosphorus (TP) load in the Flesk (Leane) sub-catchment 2071–2100 for the A2 and B2 greenhouse gas emission scenarios.

showed a similar pattern to that for Leane, with an increase in temperature of between 1.5°C and 4.0°C and a shift towards wetter winters and drier summers. Modelled effects of these changes were increased summer soil moisture deficits extending well into the autumn. The increases in temperature and soil moisture deficits contributed to projected increases in DOC concentration for both the A2 and B2 emissions scenarios. Again, this effect was more pronounced for the simulations based on the warmer A2 scenario. Additional work completed during ILLUMINATE highlighted the potential impact of projected changes in water temperature in the Burrishoole catchment on freshwater survival of salmon (McGinnity et al., 2009).

4.3 Demonstration Workshop

As part of the ILLUMINATE project a 1-day EPA-approved demonstration workshop was conducted on 4 July 2009 in Trinity College University of Dublin (Appendix 1). The workshop examined how an integration of empirical data, predictions of future climate conditions and dynamic modelling can be used to address important lake-management-relevant knowledge gaps and was attended by environmental managers, policy makers, regulators and scientists with an interest in freshwater bodies and their catchments.

5 Current 'At Risk' Characterisation

Lakes in Ireland with a surface area >50 ha have recently been characterised according to the likelihood of their meeting the requirements of the WFD by the end of the current implementation period (i.e. by 2015). There remains some concern among scientists, environmental regulators and policy makers over the uncertainties in the characterisation exercise. Based on a combination of empirical data and modelled output, covered in brief in this summary report and in greater detail in the End of Project Report (Dalton et al., 2010) available at http://erc.epa.ie/safer/reports, the original characterisation of Leane and Mask as 'at significant risk' of not meeting the requirements of WFD (Anonymous, 2005) would appear correct. However, while the available evidence supports the characterisation of Muckross as 'probably not at significant risk', the same cannot be said for Feeagh in the Burrishoole catchment. Rather, this site would appear to be 'at significant risk' of not meeting the requirements of the WFD because of its nutrient-enriched state and the continued presence in the catchment of the responsible drivers (afforestation and erosion).

6 Conclusions

Focusing on three catchments and associated lakes and divided into four integrated WPs, ILLUMINATE aimed to:

- Establish reference conditions and determine aquatic ecological responses to particular and combined past pressures;
- Use coupled dynamic ecological pressure-response models in combination with existing and new environmental information to simulate past and future scenarios of direct relevance to implementation of the WFD in Ireland; and
- Provide informed comment on the 'at risk' characterisation of the study lakes, where possible**.**

The ILLUMINATE mandate to make best use of existing research infrastructure and available data guided the choice of the study catchments. The mandate also required ILLUMINATE to engage as closely as possible with previously funded research projects of a similar nature, such as IN-SIGHT and CLIME, with relevant contemporaneous research projects, for example EURO-LIMPACS, and with the activities of the WRBD and SWRBD. Arriving at the conclusions that follow, which relate directly to the above aims, was greatly facilitated through engagement with previous and ongoing relevant research and with those directly involved in the management of waterbodies in the three study catchments.

1. Quantitative reconstructions of historical in-lake TP using fossil diatom assemblages and computer-based modelling of past conditions enabled the trophic status of the study lakes to be established for the time period prior to available monitoring data. While there is some overestimation of TP concentrations using DI-TP, all estimates are in general agreement and provide a basis for confidence in the value of the approach adopted in ILLUMINATE.

2. Dynamic modelling of individual and combined ecological pressures, in the form of projected climate, land-use and population changes, and their in-lake physical effects, highlighted the potential for increases in phosphorus export from the study catchments. Projected increases in transfers of phosphorus attributable to climate change potentially could be mitigated via changes in practice at farm, local and national levels, highlighting the desirability of including consideration of future changes in climate when undertaking modelling in support of decision making in catchment management.

3. Modelling of the in-lake responses to projected changes in nutrient and sediment loading and climate indicated the potential for increases in phytoplankton biomass and a shift in maximum biomass to earlier in the year.

4. Palaeolimnology-based reconstructions and model output representing past conditions support the current 'at significant risk' designation for Leane and Mask and the 'probably not at significant risk' designation for Muckross. The characterisation of Feeagh as 'probably not at significant risk' is not supported, however. Continued catchment pressures, leading to nutrient levels being maintained above reference, severely jeopardise successful attainment of the WFD objectives for this site by the end of the current implementation period (i.e. 2015).

5. Climate change is now confounding and potentially exacerbating existing problems and represents a major challenge for how freshwaters might be managed sustainably in future. The case for considering climate change in tandem with changes arising from planning and policy decisions in the management of RBDs is compelling.

6. Aside from meeting the main research aims, ILLUMINATE acts as a demonstration of the utility

and potential benefits of combining computer-based modelling of catchment and associated lake ecosystem condition and linkages with other sources of information. In ILLUMINATE, the latter comprised existing documentary and instrumental evidence and data from ecological and sedimentological analyses. This information can be used to fine-tune model output, and as a basis for realistic future scenarios. Moreover, the approach adopted in ILLUMINATE is flexible, readily updatable as new technologies and data become available, and highly portable.

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Acronyms and Abbreviations

^{137}Cs	Caesium isotope
^{210}Pb	Lead isotope
CAEDYM	Computational Aquatic Ecosystem Dynamics Model
DI-pH	Diatom inferred pH (reconstructed epilimnic pH)
DI-TP	Diatom inferred total phosphorus (reconstructed epilimnic total phosphorus)
DOC	Dissolved organic carbon
DYRESM	Dynamic Reservoir Simulation Model
EPA	Environmental Protection Agency, Ireland
ERTDI	Environmental Research Technological Development and Innovation
ESBI	ESB International
EU	European Union
GCM	Global Climate Model
GWLF	Generalised Watershed Loading Functions
ILLUMINATE	Past, current and future **I**nteractions between pressures, chemica**L** status and bio**L**ogical q**U**ality ele**M**ents for lakes **IN** contr**A**sting catchmen**T**s in Ir**E**land
NAO	North Atlantic Oscillation
P	Phosphorus
RBD	River Basin District
RCM	Regional Climate Model
STP	Sewage treatment plant
SWRBD	South Western River Basin District
TN	Total nitrogen
TP	Total phosphorus
WFD	Water Framework Directive
WP	Work package
WRBD	Western River Basin District
CLIME	Climate and Lake Impacts in Europe
IN-SIGHT	Identification of Reference Status for Irish lake Typologies Using Palaeolimnological Methods and Techniques
EURO-LIMPACS	Integrated Project to Evaluate the Impacts of Global Change on European Freshwater Ecosystems
REBECCA	Relationships between ecological and chemical status of surface waters
WISER	Water bodies in Europe: Integrative Systems to assess Ecological status and Recovery

Appendix 1 ILLUMINATE Demonstration Workshop

A key deliverable of the ILLUMINATE project was to organise a demonstration workshop aimed at environmental managers, policy makers, regulators and scientists with an interest in freshwater bodies and their catchments. The 1-day workshop examined how an integration of empirical data, predictions of future climate conditions and dynamic modelling can be used to address important lake-management-relevant knowledge gaps. The morning session included a description of the context for (David Taylor) and approaches adopted (Catherine Dalton and Eleanor Jennings) in the EPA-funded ILLUMINATE project. This was followed by a hands-on computer experience in the use of a suite of dynamic models that can be used to inform current planning at catchment and RBD levels. Guest lectures by Prof. Rick Battarbee (University College London) and Dr Ken Irvine (Trinity College University of Dublin) provided an insight into similar integrated research that has been and is being carried out on a pan-European scale (e.g. EURO-LIMPACS, REBECCA and WISER). The workshop ended with a round-table discussion.

Table A1.1. List of ILLUMINATE workshop participants.

Name	Organisation
Almeida, Gleby	glebyalmeida@gmail.com
Barry, Aidan	South Western Regional Fisheries Board
Barry, Chris	Agri-Food and Biosciences Institute, Belfast
Battarbee, Rick	University College London
Beckett, Brian	Eastern Regional Fisheries Board
Benzie, John	University College Cork
Blacklocke, Seán	University College Dublin
Bosch, Kim	Trinity College University of Dublin
Broderick, Ciaran	National University of Ireland, Maynooth
Cassina, Filippo	University of Limerick
Dalton, Catherine	University of Limerick
Donohoe, Michael	Environmental Protection Agency
Drinan, Tom	University College Cork
Duggan, Pat	Department of the Environment, Heritage and Local Government
Earle, Ray	WFD Eastern River Basin
Flynn, Ray	Queens University Belfast
Free, Gary	Environmental Protection Agency
Irvine, Ken	Trinity College University of Dublin
Jennings, Eleanor	Dundalk Institute of Technology
Kavanagh, Mark	Trinity College University of Dublin
Lenihan, David	Kerry County Council
Linnane, Suzanne	Dundalk Institute of Technology
MacDonagh-Dumler, Jon	National University of Ireland, Galway
McGinnity, Philip	Marine Institute/University College Cork
McGloin, Noel	Environmental Protection Agency
McGuinness, Martina	Carlow Institute of Technology
Melland, Alice	Teagasc
Murnaghan, Sarah	Eastern Regional Fisheries Board
O'Carroll, Ellen	Trinity College University of Dublin
O'Connor, Áine	National Parks & Wildlife Service
O'Dwyer, Barry	Trinity College University of Dublin
Ryan, Diarmuid	Eastern Regional Fisheries Board
Sparber, Karin	University of Limerick
Taylor, David	Trinity College University of Dublin
Thompson, Enda	Shannon Regional Fisheries Board
Tierney, Deirdre	Environmental Protection Agency
Tracey, Elaine	Trinity College University of Dublin
Tuite, Barrie	Trinity College University of Dublin
Wemaere, Alice	Environmental Protection Agency

Appendix 2 ILLUMINATE Main Outputs

Peer-Reviewed Publications

Allott, N. and Jennings, E., 2008. Rainfall Distribution in a catchment in SW Ireland: Implications for catchment modelling. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie* **30:** 341–344.

Chen, G., Dalton, C. and Taylor, D., 2010. Cladocera as indicators of trophic state in Irish lakes. *Journal of Paleolimnology* **44(2):** 465–481.

Dalton, C., Jennings, E. and Taylor, D., 2009. Palaeolimnology and the Water Framework Directive. Special Issue Biology and the Environment. *Proceedings of the Royal Irish Academy* **109B(3):** 161–174.

Dalton, C., Jennings, E., Taylor, D., O'Dwyer, B., Murnaghan, S., Bosch, K., de Eyto, E. and Sparber, K., 2010. *Past, current and future Interactions between pressures, chemicaL status and bioLogical qUality eleMents for lakes IN contrAsting catchmenTs in IrEland*. EPA/ERTDI Project No. 2005-W-MS-40. End of Project Report. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland. 291 pp. Available at http://erc.epa.ie/safer/reports.

Donohue, I., Bosch, K., Chen, G., Dalton, C., Leira, M., Murnaghan, S., O'Dwyer, B. and Taylor, D., 2010. Landscape characteristics determine whether ecosystems are stabilized or destabilized by nutrient enrichment. *(*Submitted)

Jennings, E., Dalton, C., Olas, M., de Eyto, E., Allott, N., Bosch, K., Murnaghan, S. and Taylor, D., 2008. Reconstruction of the recent past in a west of Ireland catchment. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie* **30:** 512–514.

Jennings, E., Allott, N., Pierson, D., Schneiderman, E., Lenihan, D., Samuelsson, P. and Taylor, D., 2009. Impacts of climate change on phosphorus loading from a grassland catchment – implications for future management. *Water Research* **43:** 4316–4326.

Leira, M., Dalton, C., Chen, G., Irvine K. and Taylor D., 2009. Patterns in freshwater diatom community distinctness along an eutrophication gradient. *Freshwater Biology* **54(1):** 1–14.

McGinnity, P., Jennings, E., de Eyto, E., Allott, N., Samuelsson, P., Rogan, G., Whelan, K. and Cross, T., 2009. Impact of naturally spawning captive bred Atlantic salmon on wild populations: depressed recruitment and increased risk of climate mediated extinction. *Proceedings of the Royal Society B: Biological Sciences* **276:** 3601–3610.

International/National Conference Presentations

Allott, N. and Jennings, E., 2007. *Rainfall Distribution in a Catchment in SW Ireland: Implications for Catchment Modelling*. Societas Internationalis Limnologiae (SIL) 30 Congress 12–18 August 2007 Montreal, Canada.

Dalton, C., Dwyer, B., de Eyto, E., Allott, N. Bosch, K., Jennings, E. and Taylor, D., 2009. *Reconstruction of the Recent Past in a West of Ireland Catchment*. 11th International Paleolimnology Symposium 15–18 December 2009, Guadelajara, Mexico.

Jennings, E., Dalton, C., Olas, M., de Eyto, E., Allott, N., Bosch, K., Murnaghan, S. and Taylor, D., 2007. *Reconstruction of the Recent Past in a West of Ireland Catchment*. Societas Internationalis Limnologiae (SIL) 30th Congress 12–18 August 2007, Montreal, Canada.

Jennings, E., Allott, N., Olaya-Bosch, K., Olas, M., Dalton, C. and Taylor, D., 2008. *Modelling Past Trophic Status in Irish Lakes*. Environ 2008.

Jennings, E., Allott, N., Olaya-Bosch, K., Olas, M., Dalton, C. and Taylor, D., 2008. *The Role of Hindcast Modelling and Palaeolimnology in Supporting the Water Framework Directive.* IWWE 2008 seminar 'Water Framework Directive – Half Way There?' RDS, Dublin, Ireland. March 2008.

Murnaghan, S. et al., 2008. *Teagasc 'Grasslands and the Water Framework Directive' Conference.* Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland. 12–14 November 2008.

Taylor, D., 2008. *Climate and Catchment Changes and Ensuring the fUture Health of Aquatic Ecosystems: Linking an Improved Understanding of the Past to Policy-Making and Management*. EPA Environmental Research Conference, 6–7 February 2008.

PhD Theses

Murnaghan, S. PhD working title: *Modelling Ecological Pressures and Responses in a Complex Lake.*

Olaya-Bosch, K. PhD working title: *Using Palaeolimnological Techniques to Analyse Past and Present Status of Lakes in Ireland.*

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

Environmental Protection Agency
An Ghníomhaireacht um Chaomhnú Comhshaoil

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SSTI Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government